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ANALYSIS OF

INVENTORY RECORD ACCURACY

by

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ABSTRACT:

The inventory record accuracy problem was studied using a complex simulation model of stock point supply operations. Complete item and error data were obtained from various sources within the Navy Supply System. The experiments performed indicated that the presence of stock record errors degraded supply operations, in terms of quantified measures, and that in an environment of imperfect receipt and issue processing and physical inventories, supply effectiveness was not related to record accuracy. A rational criterion for determining the optimal physical inventory policy was developed.

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1. SUMMARY

This report describes a quantitative analysis of the inventory record accuracy problem. A complex simulation model of stock point operations with a stock battery of over 500 items was employed to study the influence of stock record errors on supply operations and the relative efficiency of various physical inventory policies.

Supply operations were described in terms of the requisition fill rate, total backorder-days, inventory record accuracy, backorder releases, warehouse refusals, unrealized assets, total buys, actual inventory investment, and other measures.

The item data was obtained from a random sample of DSA items at NSC Newport. Data on the frequency of introduction of various types of errors in receipts and issue processing and in selected item inventories was obtained from NSC Oakland. Data on the accuracy of wall-to-wall physical inventories was taken from a report prepared by the former Navy Supply Research and Development Facility at Bayonne. Physical inventory cost data was obtained from the Fleet Material Support Office.

The results of this research indicated:

1. that supply operations were indeed hampered by the presence of stock record errors;

2. that, within an environment of error introduction to stock records and imperfect physical inventories, supply effectiveness (requisition fill rate and/or backorder-days) was <u>not</u> related to record accuracy;

3. that the selected-item prior-to-buying physical inventory policy now employed in the Navy Supply System was not the most effective of the physical inventory policies studied; and

4. that a method for rationally evaluating physical inventory policies has been demonstrated.

The sections which follow in this report provide an introduction to the record accuracy problem and the approach taken, a complete description of the simulation model and data employed, a description of the experiments performed and results obtained, and a complete analysis of these results and statements of the conclusions drawn.

2. INTRODUCTION

This report is concerned with the problem of errors in inventory stock records. For some time the General Accounting Office has expressed concern about the ability of the armed forces to account for inventories of material (1). Increasing concern has also been exhibited for the impact of stock record errors on the ability of Navy stock points to perform their fleet support mission (2).

A stock record contains many data fields. The question of record accuracy usually boils down to whether the recorded on-hand quantity is in agreement with the physical stock actually on hand, though it has been suggested that more comprehensive definitions of record accuracy may be required (3). Positive errors have been defined as those where the actual on-hand quantity exceeds the quantity indicated on the stock record. Negative errors describe a condition where there is less material available for issue than the records indicate (4).

It is clear that stock record errors influence supply operations and supply effectiveness. A positive error on a stock record represents a situation where material is available for issue but may not be utilized because the stock point does not know of its existence. A negative error can generate a warehouse denial when the stock point attempts to issue material thought to be available, but which in fact is non-existent. The above arguments apply to stock record errors at the stock point. At the system level, the inventory control point (ICP) will reorder stock too soon or too late depending upon whether there are positive or negative errors in its records. Ordering too soon by the ICP amounts to a mis-allocation of

procurement funds and ordering too late (by the ICP) will manifest itself in reduced availability of material for issue.

Errors are generated in stock records through actions which cause changes in the physical quantity of material on hand and those actions which cause changes in the recorded on-hand quantity. In particular, discrepancies are introduced in the processes of receiving and issuing material, as well as by unauthorized removals of material. Additionally, errors may be generated by adjustments of records for various reasons including cog transfers, changes in unit of issue, and conspicuously, those resulting from the physical inventory process.

Stock record errors are found and corrected by physical inventories. "Physical inventory" connotes a program to count the quantity of an item in storage, to compare the count with amount recorded on the stock record, and to reconcile any discrepancy. Several types of physical inventories are possible; the most common are the wall-to-wall inventory and the spot inventory of selected items. Navy physical inventory policy has changed a number of times over the last ten years indicating that the best physical inventory program is difficult to determine. The complexity and difficulty of the inventory record accuracy problem cannot be overestimated.

There are two ways of improving stock record accuracy: (1) to reduce or eliminate errors introduced into the records in receipt, storage, and issue operations; and (2) to improve the accuracy and timeliness of the discovery and correction of errors. It is no secret that physical inventories are themselves not highly accurate. Reaction to the problem of stock record accuracy has been marked by a commitment to improve accuracy for the sake of accuracy.

3. STUDY APPROACH AND OBJECTIVES

The basic viewpoint taken in this study is that record accuracy should be improved only up to the point where the cost of record accuracy is less than the benefits derived from improved record accuracy. The viewpoint just described is the standard notion of optimization, or cost-benefit analysis, applied to the stock record accuracy problem. It is a simple, common-sense, intuitively-appealing idea.

While the overall basis of analysis is simple, it generates some difficult problems. The major problem is to determine the benefit of improved accuracy or the costs of inaccurate records. The determination of the benefits of improved accuracy has been an unsolved problem. Without this answer it has been difficult to justify allocation of resources to physical inventory and quality assurance programs.

Requirements for the valid determination of the benefits of record accuracy include knowledge of the generation of errors and error magnitudes and a robust model of supply operations. The model of supply operations should represent a stock point; that is, a multi-item rather than a single-item model is required, since there are interactions and dependencies between items. Examples are the posting of a receipt to the wrong item record or the issuing of the wrong item.

In view of the need for detailed analysis of error generation processes and for a large, multi-item model of stock point operations, simulation was chosen as the primary modeling technique. By use of a simulation of stock point operations, including receipts and issues with errors, replenishment of stock, and requisitions, various physical inventory programs

can be evaluated with respect to their influence on record accuracy and supply effectiveness.

The specific objectives of the study may now be stated as:

1. determination of the effect of various record accuracy levels upon supply operations;

2. evaluation of various physical inventory programs; and

3. conclusions about the optimal physical inventory program.

4. THE MODEL AND DATA

4.1 General Approach

The system modeled is that of a single manager, single warehouse, multi-item inventory system corresponding to a typical Navy Supply Depot. A simulation, rather than an analytical model, is employed. The selection of simulation allows a very richly detailed model with minimal assumptions.

The simulation includes receipt and requisition processing, replenishment, and physical inventory processes. It is very nearly a general purpose inventory system model with a multitude of uses. The exact form of the model, of course, reflects a great deal of structure concerned with stock record error generation and correction. Every attempt has been made to make the simulation program, written in FORTRAN IV, as easy to understand as possible. The labels were chosen to be meaningful, so that one may view the program as the manipulation of records and quantities which are real entities in actual practice.

Two inventory options are available within the simulation: a complete wall-to-wall, with the interval between inventories as specified by the user; and a selected item inventory just prior-to-buying, which causes a scheduled* inventory to be conducted on an item just before a buy is made on that item. The length of the simulation is also selected by the user. Certain statistics are computed daily, which are used to generate annual reports. In addition, the results of each wall-to-wall inventory

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*The following terminology is employed with respect to selected item physical inventories. A spot inventory is conducted in connection with a warehouse refusal. A scheduled inventory is performed in connection with a prior-to-buying physical inventory policy.

are printed, in conjunction with statistics which have been generated during the period since the last wall-to-wall inventory. Throughout the entire daily routine, as well as during the inventories, errors are being generated based on data presently available. At the end of the simulation, a summary of the entire run is printed, which can be used to evaluate the inventory option employed.

4.2 The Data

The item data consists of information extracted from a random sample of 505 items taken ten months after a wall-to-wall inventory was conducted at NSC Newport in 1965. Of the sample of 505 items, all 187 DSA items were chosen for the present simulation. These 187 items represent a 1% random sample of the approximately 18,000 DSA items stocked at NSC Newport. Only the DSA items were used since inventory policies (reorder points and order quantities) could not be determined (from records) for non-DSA items. This particular sample was chosen for its unique qualities: namely that, through the efforts of Navy Supply Research and Development Facility (NAVSUPRANDFAC) (4) personnel, both the recorded and actual on-hand quantities were known. This alleviated the need to make an assumption about these quantities at the start of the simulation. The simulation employs a stock battery of 561 items which is a simple triplication of the basic 187 item sample.

The price and demand characteristics of the item sample were as follows. The average price of the items used in the simulation is $6.10 with a range of from $0.01 to $313.00. The average mean annual demand for the sample items is 148 units with a range of from 1 to 12,800 units.

There were 112 items with annual demand of less than 10 units, 39 items with demand of from 10 to 99 units, and 36 items with demand of 100 units or more.

The item characteristics selected for input to the simulation are:

- serial number, arbitrary (SERIAL)*;
- unit price (PRICE);
- recorded on-hand quantity (RECOH);
- actual on-hand quantity (ACTOH);
- dues outstanding (DUES);
- reorder quantity (Q);
- reorder point (RP);
- mean quarterly demand (DBAR);
- mean procurement lead time in quarters (LT); and
- mean absolute deviation of quarterly demand (MAD).

Several sources of data on the accuracy of wall-to-wall physical inventories were available. Rinehart (5) reported that between 24% and 26% of all record errors are contributed by the physical inventory process and reports situations where records were more accurate <u>before</u> a wall-to-wall inventory than after. NAVSUPRANDFAC (4) reported that the wall-to-wall physical inventory process is 92.9% accurate and provided the empirical distribution of the errors. More recently, the Fleet Material Support Office (FMSO) informally reported that the wall-to-wall physical inventory process is only 87.5% accurate.

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*refers to a label used in the prgram as the name of either a datum or variable. See Appendix A.

The NAVSUPRANDFAC wall-to-wall physical inventory accuracy data is used in the simulation because of its completeness. The data indicate that for a wall-to-wall inventory, the count is correctly made 92.9% of the time. For the other 7.1% of the time, errors are assumed to be normally distributed, with a mean error quantity of zero, and a standard deviation derived from the data as follows:

ACTOH	Standard Deviation
1-10	1.87
11-20	4.65
21-100	2.20
101-	11.80

When an error is generated, the magnitude of the error is at least one unit.

Data on receipt and issue errors were obtained from the Quality Assurance and Internal Review Division of NSC Oakland. These data indicate that 95.99% of the time, the quantity ordered equals the quantity received, and the receipt is processed correctly (RECTOK). For the other 4.01% of the time, errors occur as follows:

- 1.37%: received 8% more than ordered (RECTEO)
- 1.38%: received 6% less than ordered (RECTEU)
- 0.64%: receipt not posted (RECTNP)
- 0.62%: receipt posted to wrong stock record (RECTPW).

For issue processing, the issue is correctly processed 97.74% of the time (ISSOK). For the other 2.26% of the time, errors occur as follows:

- 0.73% overissue (ISSEO)

  - 0.48% overissue by 7%

  - 0.18% overissue by 15%

  - 0.07% overissue by 30%

- 0.75% underissue (ISSEU)

  - 0.50% underissue by 8%

  - 0.12% underissue by 20%

  - 0.13% underissue by 50%

- 0.78% issue wrong item (ISSWID).

Data on scheduled inventories were also provided by NSC Oakland, and indicated that the scheduled inventory is performed correctly 96% of the time. For the other 4% of the time, errors occur as follows:

- 1%: errors are plus or minus 1
- 1%: errors are plus or minus 2
- 2%: errors vary from 5 to 100, as a function of ACTOH.

For spot inventories the assumption is made that an accurate reconciliation is made 97% of the time and that the record remains unchanged 3% of the time. This is a crude assumption, but fortunately the spot inventory plays a very minor role in the simulated inventory operations.

Data on inventory costs were provided by FMSO (6). For conducting a wall-to-wall inventory, the cost is estimated to be $1.09 per item. For conducting a selected item inventory, the cost is estimated to be $3.85. A spot inventory was estimated to cost $3.92. These costs include reconciliation, in addition to the physical counting process.

4.3 Underlying Distributions

DBAR and MAD item demand data from FMSO records is used to specify the parameters of the item demand generation processes. Realistic simulation requires that requisitions be generated over time in some fashion, and that the total number of items requisitioned per quarter approximate DBAR. Both the time between successive requisitions on an item and the size of the requisitions must be specified. To assume that all requisitions are for a quantity of one would be misleading since the total number of requisitions the system would have to process would be too large. Since each requisition and the attempted issue which follows from the requisition can generate errors, it is important that a variable requisition size be used.

The assumption made in this study is that item demand follows a "stuttering Poisson" distribution; that is, that the time between successive demands is exponentially distributed and that the requisition size has a geometric distribution on the positive integers. The method of moments is used to estimate the parameters of the stuttering Poisson from DBAR and MAD for each item. Equations for these estimates are developed in Appendix B.

The daily operations of a stock point are dynamic, and any model which attempts to simulate such operations must provide the randomness which is needed. In the above, the underlying distributions for the simulation were stated, with no indication of how these distributions were to be generated. In order to provide the randomness called for, and to meet the basic criteria of the distributions as stated above, pseudo random numbers are generated which are inputs to subroutines which output random variables with various distributions as required. The stream of numbers is random in that it meets certain statistical tests for randomness, and is pseudo

in that any given stream of random numbers can be reproduced. In the present simulation, the IBM subprogram RANDU is used to generate three different streams of random numbers: one for generating demands, one for generating errors of various types, and one for all other uses. These three different streams allow comparisons to be made between different inventory policies. It is assumed that a valid comparison of inventory policies is possible only when the stock sample being used faces the same pattern of demand from run to run. This scheme also provides for allowing runs to be made with no errors at all, these "clean" runs providing a benchmark for the "dirty" runs (those runs in which errors are introduced).

4.4 The Vector Framework

The basic framework of the simulation is two vectors: a stock record or item vector, and a buy vector. An item vector has various components which allow the item to be identified, and which allow the status of the item to be maintained. The components of each item vector are: SERIAL, PRICE, RECOH, ACTOH, DUES, Q, RP, DBAR, LT, and MAD, as defined in Section 4.2 and, in addition, the following:

- quantity presently backordered (BO);
- total dollar value of buys to date (CUMBUY);
- demand parameters (P, NU);
- date of next requisition (NXTREQ);
- total cumulative demand to date (CUMDMD); and
- total cumulative backorder days to date for this year (BODAYS).

The subscript I is employed throughout the simulation to refer to the Ith item; for example, if I = 25 , then PRICE(I) is the unit price of item number 25.

The second vector is the buy vector, which consists of the following components:

- the item number to which the buy applies (INDEX);
- the quantity ordered (ORDQN); and
- the due date of the material (DUEDAT).

The subscript J is employed throughout the simulation to refer to the Jth buy; for example, if J = 681 , then INDEX(J) holds the item number for which the 681st buy was made, e.g., item number 25. The use of these vectors will be clarified in the following paragraphs.

4.5 Program Operations and Control

The reader's attention is invited to the system flow chart, as well as the detailed flow charts, to be found in Appendix C. The present discussion will provide a narrative clarification of these charts, and is intended to provide an appreciation of the logical construction of the model. A thorough knowledge of the model would require a study of the program itself, in conjunction with the detailed flow charts.

After the standard initialization procedures, the item data is read, after which the user, assumed to be controlling the program through a time-sharing terminal, is queried for the length of the simulation, the type of run (clean or dirty), the demand random number streams initializer (INITRN), and the inventory option desired. The value of INITRN is arbitrary and merely provides for a constant demand pattern from run to run

if desired. The simulation is now independent of the user, and proceeds as follows. Due dates are computed for any outstanding dues at the beginning of the simulation, by assuming that all material will arrive during the first sixty days of the run in accordance with a uniform distribution. Then the parameters of the stuttering Poisson demand generators are computed from item DBAR and MAD data. Dates of first requisitions for each item (NXTREQ) are computed using the exponential distribution, and all records are scanned to determine if buys are necessary. (Conceptually, the generation of dates for the next requisition to occur is a type of 'event-store' process, in which the occurrence of a particular type of transaction causes the generation of the time for the next transaction of the same type to occur.)

The decision as to whether to make a buy is made by the subroutine BUY by computing the inventory position (IP) of the item, defined to be the recorded on-hand quantity (RECOH) plus outstanding dues (DUES) minus backorders (BO). If the inventory position is less than or equal to the reorder point (RP), an order is generated for the integer multiple of the order quantity (Q) which will bring the inventory position up to a point between RP and RP + Q.

Having completed the initialization procedures for day one, the daily routine begins. Each day is identified by an integer number; the present day at any time is the value of the variable TODAY. Thus the simulation begins with TODAY equal to one, and time-steps through to TODAY equal to FINISH, which is the last day of the simulation.

The daily routine begins with receipt processing, which consists of scanning the list of outstanding orders to see if any dates in the DUEDAT vector match the date in TODAY. If there is a match for a particular item,

a random number is generated to determine whether the receipt will be processed correctly, or with errors. After the receipt is processed (See detailed flow chart, Appendix C), a check is made to determine if there are any backorders outstanding for that item. If so, an attempt is made to release the backorders. (Note: even though requisitions of different sizes are generated, only the total quantity of each requisition backordered is recorded in BO. No provision is made to distinguish a backorder resulting from one requisition from that resulting fron any other requisition. Thus, the simulation can only keep statistics on time-weighted unit backorder days, it does not accumulate statistics on the number of requisitions which have been backordered.) Backorder releases are very similar to regular issues, in which the record is checked to determine if an attempted issue should be made, after which the actual on-hand quantity is checked in order to actually effect the issue. In the case of a backorder release, an attempted issue quantity (ISSQN) assumes the value of the present number of backorders (BO), and a determination is made of whether an actual issue can be made. If so, the subroutine ISBOER (See detailed flow chart, Appendix C) is called to make the backorder release subject to errors.

After each issue of material on an item, whether to release a backorder or to satisfy a requisition, a check of the new inventory position is made. If the new inventory position is at or below the reorder point, a buy is made in order-quantity multiples to bring the inventory position back up to the (RP, RP + Q) interval.

After the receipt and backorder processing is completed, all requisitions are processed. The component NXTREQ is checked against TODAY to determine if there is to be a requisition today for the particular item in

question. If so, the requisition size (REQSIZ) is generated using the geometric distribution, and a new NXTREQ is generated for the item from its exponential inter-demand time distribution. As in the backorder release routine, the attempted issue quantity (ISSQN) is determined by REQSIZ, and both the recorded on-hand quantity (RECOH) and the actual on-hand quantity (ACTOH) are checked to see if the issue can be made. If necessary, a warehouse refusal is generated which results in a spot inventory being taken, subject to errors. The actual issue is made by calling the subroutine for making issues with errors (ISSERR), the flowchart of which is not included since it is so similar to ISBOER.

The end of the day brings the daily update to keep track of such items as total accumulated unit backorder days to date this year (BODAYS), the record accuracy at the end of the day, and the dollar value of investment recorded and actually held on hand. If today is the day for a wall-to-wall inventory, the subroutine WALLOP is called. If today is the end of a year, the annual report is generated. If today is the end of the quarter, the subroutine QTR$ is called to compute the dollar value of demand for this quarter and the dollar value of buys for this quarter. If today is the end of the simulation, the summary is generated. If today is not the last day, the variable TODAY is incremented, and the daily routine begins again.

4.6 The Output

The purpose of the study was to determine the effects of record accuracy upon measures of effectiveness and costs for the system. Accordingly, the output of the simulation was designed to allow comparisons over time of certain statistics, as well as to allow evaluation of the entire run. Table 4.1 is a typical annual report.

TABLE 4.1: TYPICAL ANNUAL REPORT

SUPPLY PERFORMANCE MEASURES:

CUMREQ =	2791		
COMPFL =	2454	=	87.93 Per Cent of CUMREQ
PARTFL =	316	=	11.32
ACOMFL =	2487	=	89.11
APARFL =	304	=	10.89
ABOREL =	123		
BOREL =	123		
TOTAL BODAYS (BODTOT) =	661227		
BUYS =	722		
REFUSL =	7		

ERROR MEASURES:

RECTOK =	694	=	95.33 Per Cent of Total Receipts
RECTEO =	14	=	1.92
RECTEU =	10	=	1.37
RECTNP =	5	=	0.69
RECTPW =	5	=	0.69
ISSOK =	2850	=	98.04 Per Cent of total Issues (Includes BO releases)
ISSEO =	22	=	0.76
ISSEU =	15	=	0.52
ISSWID =	20	=	0.65

QTR	DEMAND$	BUY$
5	20710.69	20811.81
6	20371.13	19452.00
7	15642.81	15522.56
8	17774.37	17279.88

Each measure applies only to the year immediately preceding the day of the report. The measures are defined as follows:

- CUMREQ: total number of requisitions;
- COMPFL: number of requisitions completely filled on demand;
- PARTFL: number of requisitions partially filled on demand;
- ACOMFL: number of attempted complete fills;
- APARFL: number of attempted partial fills (the difference which may result in actual versus attempted is due to the effects of record inaccuracies);
- ABOREL: number of attempted backorder releases;
- BOREL: number of actual backorder releases;
- TOTAL BODAYS (BODTOT): total unit backorder days, in millions;
- BUYS: number of buys; and
- REFUSL: number of warehouse refusals.

The error measures are the same as those stated above in Section 4.2, and represent the mean accuracies of the stochastic processes generating receipt and issue errors. DEMAND$ and BUY$ provide the dollar values of quarterly demand and buys for the quarter indicated.

When the wall-to-wall inventory option is selected, a report of the inventory results and statistics accumulated since the last wall-to-wall inventory are printed. Table 4.2 is an example of such a report.

TABLE 4.2: TYPICAL WALL-TO-WALL INVENTORY REPORT

728	=	DAY WALL-TO-WALL INVENTORY HELD
89.48	=	PER CENT RECORDS ACCURATE JUST PRIOR TO INVENTORY
90.82	=	MEAN PER CENT RECORD ACCURACY DURING PERIOD
88.77	=	MINIMUM PER CENT RECORD ACCURACY DURING PERIOD
50456.00	=	MEAN DOLLAR VALUE OF RECOH DURING PERIOD
45360.80	=	MINIMUM DOLLAR VALUE OF RECOH DURING PERIOD
50372.13	=	MEAN DOLLAR VALUE OF ACTOH DURING PERIOD
45386.03	=	MINIMUM DOLLAR VALUE OF ACTOH DURING PERIOD
91.80	=	PER CENT RECORDS ACCURATE JUST AFTER INVENTORY

Information from both of the above reports is accumulated for the summary at the end of the simulation. The summary consists of two parts, one of which summarizes information collected on an annual basis, the other of which summarizes information related to the wall-to-wall inventory periods. If the PBUY inventory option is selected, the periodic portion of the report contains information accumulated annually. Table 4.3 is a typical summary.

The annual portion of the summary is derived from the individual annual reports which are generated as the simulation proceeds. DIFF is the difference between COMPFL and PARTFL, and represents those requisitions which resulted in a backorder for the full amount of the requisition (a 'no-fill'). The periodic portion of the report shows the inventory period by number, the mean record accuracy for the period (RECACC), and the mean dollar value of investment during the period, both recorded (RECOH$)

TABLE 4.3: TYPICAL SUMMARY REPORT

SUMMARY STATISTICS

ANNUAL:

YEAR	COMPFL NO.	PC	PARTFL NO.	PC	DIFF NO.	PC	BOREL	BODAYS	BUYS	REFUSL
1	2583	92.9	167	6.0	29	1.0	70	109269	904	11
2	2454	87.9	316	11.3	21	0.8	123	661227	722	7
3	2446	86.1	379	13.3	17	0.6	180	1147651	771	8
4	2460	88.1	308	11.0	24	0.9	135	835196	742	10
5	2320	83.4	442	15.9	20	0.7	179	1195012	748	9
6	2395	83.7	440	15.4	27	0.9	176	976435	782	10
7	2435	84.9	413	14.4	21	0.7	147	1046662	746	7
8	2229	83.7	415	15.6	20	0.8	164	620770	703	11
MEAN	2391	85.4	387	13.8	21	0.8	157	926136	744	8

PERIODIC:

PERIOD	RECACC	RECOH$	ACTOH$
1	93.7	57047.07	57077.49
2	90.8	50456.09	50372.13
3	88.6	49017.62	49021.89
4	92.9	48331.78	48077.89
5	92.2	49379.91	49006.15
6	90.4	46168.09	46159.95
7	90.1	49586.15	45575.49
8	92.2	46527.82	45575.49
SUM	730.9	396534.37	395272.81

and actual (ACTOH$). This latter value of mean actual investment represents information which is never actually available to the stock point manager, and which will be used to cost out the effects of errors in the system. The row labelled SUM can be used to average RECACC, RECOH$, and ACTOH$ for any number of periods desired.

5. EXPERIMENTS AND RESULTS

5.1 Approach

Consistent with the study objectives as stated in Section 3, the experiments performed involved generating operating statistics in order to quantitatively compare errorless inventory system operations with inventory systems operations when errors are present, and to compare the effectiveness of wall-to-wall physical inventories with selected item physical inventories.

5.2 First Experiment: The Whole Sample

Each experiment was a series of simulation runs. The first employed the whole sample of 561 item records. Every run simulated eight years of inventory system operation. Runs were made and operating statistics were collected for the following: errorless (clean) system operations; system operations with errors being introduced and wall-to-wall physical inventories at 1, 2, 3, 4, 6, 8, and 12 quarter intervals; and system operations with errors and a selected-item scheduled inventory just prior to making a buy (PBUY option). Three different demand patterns were employed with each of the above three types of runs.

With each run there was a transient period during which system operating statistics stabilized. This transient period lasted for about one year; consequently, each eight-year run produced seven years of usable statistics. One reason for the transient period was that the Newport data indicated that the stock battery was only 79% accurate initially, while most runs indicated a steady state accuracy somewhat higher. For completeness, it is noted that the original Newport data produced a four-year

transient period; the economics of simulation with regard to program execution time and program size demanded a reduction in this period. The long transient period, which affected supply effectiveness statistics, was produced by the high initial asset position indicated by the Newport data. Theoretically, assets are determined by the reorder point and reorder quantity. While the reorder policies for the Newport data authorized a theoretical asset level of about $18,000, the initial assets were about $40,000. Therefore, for items with excessive assets, the initial actual inventory position was reduced to a quantity uniformly distributed on the interval [RP, RP + Q] . The recorded on-hand quantities for these items were similarly modified.

5.3 Second Experiment: Stratified Whole Sample

The second experiment was conducted with the original sample stratified into high, medium, and low demand categories. Defined in terms of estimated mean annual demand, the high, medium, and low demand categories were 100 units or greater, 10 to 99 units, and less than 10 units, respectively. Each of these demand stratified samples was expanded to yield a population of 504 items. (This number resulted from a constraint on computer core caused by the high demand sample's requiring more storage for the buy vectors.) Subsequently, for each demand category population, the clean, wall-to wall, and inventory prior-to-buying runs were made as in the first experiment, but with fewer different demand patterns.

5.4 Third Experiment: Whole Sample With Increased Protection Levels

The third experiment, suggested by the results of the first experiment, involved studying clean, wall-to-wall, and inventory prior-to-buying runs with all reorder points modified to provide 85% protection against stockout in a cycle. (A cycle for a given item is defined to be the mean time between receipts of orders.) The sample employed was the whole sample of 561 items. The original Newport reorder points provided for a 55% mean requisition fill rate (COMPFL%), broken down as follows: 35% for high demand items, 66% for medium demand items, and 71% for low demand items. Setting all reorder points at the 85% protection level produced a mean overall requisition fill rate of 86%.

The results of these experiments are presented in Tables 5.1 through 5.5. These tables represent a total of 576 years of simulated stock point operations.

TABLE 5.1. SUMMARY STATISTICS: WHOLE SAMPLE (561 ITEMS), FIRST EXPERIMENT

VARIABLE	CLEAN	WALL TO WALL INTERVAL, DAYS							PBUY
		91	182	273	364	546	728	1092	
RECACC; AVERAGE RECORD ACCURACY	100	92.8	91.6	90.3	90.1	88.1	86.5	83.6	91.4
CUMREQ; AVE. REQUISITIONS PER YEAR	2799	2799	2799	2799	2799	2799	2799	2799	2799
ACOMFL; ATTEMPTED COMPLETE FILLS	1598	1555	1552	1547	1547	1527	1533	1535	1536
COMPFL; ACTUAL COMPLETE FILLS	1598	1525	1531	1520	1500	1500	1495	1511	1506
COMPFL%; ACTUAL COMPLETE FILLS %	57.1	54.5	54.7	54.3	53.6	53.6	53.4	54.0	53.8
ACOMPFL; ATTEMPTED PARTIAL FILLS	1200	1244	1247	1252	1269	1313	1318	1258	1268
PARTFL; ACTUAL PARTIAL FILLS	1200	1241	1237	1249	1266	1268	1271	1254	1265
BOREL; BACKORDER RELEASES	444	450	450	450	456	453	453	457	454
BODTOT; BACKORDER-DAY TOTAL x 10^6	5.16	5.95	5.97	6.70	6.85	6.31	6.17	6.60	6.30
BUYS; AVE. NO. BUYS PER YEAR	754	750	749	748	748	745	749	747	746
REFUSL; AVE. NO. REFUSALS PER YEAR	0	22	22	25	25	29	27	33	22
ACTOH$; ACTUAL INVENTORY INVESTMENT	17690	17115	17141	17549	17724	17766	18336	19637	17495
ΔI; ACTOH$ - RECOH$	0	88	183	125	357	423	1070	1561	- 81
INITRN; DEMAND PATTERNS	3	3	3	3	3	3	3	3	3

TABLE 5.2. SUMMARY STATISTICS: HIGH DEMAND SAMPLE (504 ITEMS), SECOND EXPERIMENT

VARIABLE	CLEAN	WALL TO WALL INTERVAL, DAYS							PBUY
		91	182	273	364	546	728	1092	
RECACC; AVERAGE RECORD ACCURACY	100	92.4	90.3	88.6	85.6	82.8	79.0	74.3	89.7
CUMREQ; AVE. REQUISITIONS PER YEAR	5867	5867	5867	5867	5867	5867	5867	5867	5867
COMPFL%; ACUTAL COMPLETE FILLS %	38.3	35.5	36.1	35.5	35.3	35.2	35.5	35.5	35.6
PARTFL; ACTUAL PARTIAL FILLS	3618	3726	3696	3735	3744	3747	3739	3737	3736
BOREL; BACKORDER RELEASES	989	983	978	974	981	988	988	987	980
BODTOT; BACKORDER-DAY TOTAL x 10^6	22.56	26.07	26.74	28.61	26.91	26.56	26.61	26.07	28.15
BUYS; AVE. NO. BUYS PER YEAR	1271	1254	1254	1257	1255	1253	1255	1255	1250
REFUSL; AVE. NO. REFUSALS PER YEAR	0	49	44	46	48	51	50	48	38
ACTOH$; ACTUAL INVENTORY INVESTMENT	42142	40010	41173	42796	42532	43709	45978	48010	40815
ΔI; ACTOH$ - RECOH$	0	291	869	833	1735	2628	4252	4983	- 123
INITRN; DEMAND PATTERNS	2	2	2	2	2	2	2	2	3

TABLE 5.3. SUMMARY STATISTICS: MEDIUM DEMAND SAMPLE (504 ITEMS), SECOND EXPERIMENT

VARIABLE	CLEAN	WALL TO WALL INTERVAL, DAYS							PBUY
		91	182	273	364	546	728	1092	
RECACC; AVERAGE RECORD ACCURACY	100	92.5			88.0		84.4	81.3	88.4
CUMREQ; AVE. REQUISITIONS PER YEAR	3158	3158			3158		3158	3158	3158
COMPFL%; ACTUAL COMPLETE FILLS %	71.1	66.3			67.0		65.2	65.1	67.5
PARTFL; ACTUAL PARTIAL FILLS	911	1030			1008		1064	1067	995
BOREL; BACKORDER RELEASES	394	397			401		406	407	404
BODTOT; BACKORDER-DAY TOTAL $\times 10^6$	.492	.589			.609		.598	.616	.586
BUYS; AVE. NO. BUYS PER YEAR	662	660			654		657	654	659
REFUSL; AVE. NO. REFUSALS PER YEAR	0	22			30		33	38	22
ACTOH$; ACTUAL INVENTORY INVESTMENT	19353	18869			19244		20210	21226	18696
ΔI; ACTOH$ - RECOH$	0	19			285		518	1600	6
INITRN; DEMAND PATTERNS	1	1			1		1	1	1

TABLE 5.4. SUMMARY STATISTICS: LOW DEMAND SAMPLE (504 ITEMS), SECOND EXPERIMENT

VARIABLE	CLEAN	WALL TO WALL INTERVAL, DAYS							PBUY
		91	182	273	364	546	728	1092	
RECACC; AVERAGE RECORD ACCURACY	100	93.0			90.9		89.8	87.6	93.3
CUMREQ; AVE. REQUISITIONS PER YEAR	1262	1262			1262		1262	1262	1262
COMPFL%; ACTUAL COMPLETE FILLS %	75.0	71.2			70.6		71.1	71.2	70.7
PARTFL; ACTUAL PARTIAL FILLS	314	344			352		246	343	353
BOREL; BACKORDER RELEASES	210	225			227		232	225	227
BODTOT; BACKORDER-DAY TOTAL x 10^6	.051	.068			.066		.060	.061	.065
BUYS; AVE. NO. BUYS PER YEAR	502	507			499		507	505	504
REFUSL; AVE. NO REFUSALS PER YEAR	0	10			13		15	15	10
ACTOH$; ACTUAL INVENTORY INVESTMENT	6785	6665			6659		6742	6811	6677
ΔI; ACTOH$ - RECOH$	0	- 71			23		191	8	89
INITRN; DEMAND PATTERNS	2	1			2		1	1	1

TABLE 5.5. SUMMARY STATISTICS: WHOLE SAMPLE WITH 85% STOCKOUT PROTECTION (561 ITEMS), THIRD EXPERIMENT

VARIABLE	CLEAN	WALL TO WALL INTERVAL, DAYS							PBUY
		91	182	273	364	546	728	1092	
RECACC; AVERAGE RECORD ACCURACY	100	91.5	89.8		86.5			80.4	89.0
CUMREQ; AVE. REQUISITIONS PER YEAR	2798	2798	2798		2798			2798	2798
COMPFL%; ACTUAL COMPLETE FILLS %	90.6	86.2	85.1		86.5			84.8	86.0
PARTFL; ACTUAL PARTIAL FILLS	265	364	392		351			398	369
BOREL; BACKORDER RELEASES	138	168	169		167			171	168
BODTOT: BACKORDER-DAY TOTAL x 10^6	.771	1.120	1.191		.976			1.259	1.156
BUYS; AVE. NO. BUYS PER YEAR	762	759	759		756			755	749
REFUSL; AVE. NO REFUSALS PER YEAR	0	10	13		14			20	20
ACTOH$; ACTUAL INVENTORY INVESTMENT	49339	47855	48250		48111			46950	47446
ΔI; ACTOH$ - RECOH$	0	143	171		346			969	- 680
INITRN; DEMAND PATTERNS	2	2	2		2			2	2

6. ANALYSIS AND CONCLUSIONS

6.1 Preface

The pattern for all the experiments was a series of simulation runs which were either 'clean' or dirty.' The clean runs were completely error free; all receipts, issues, and backorder releases were processed accurately. The dirty runs were made with receipt, issue, backorder-release, and physical inventory errors being introduced. The clean runs, which are an abstract product of the model and not realizable in actual operations, provided quantitative measures of how inventory record errors degrade supply operations.

6.2 Analysis of the First Experiment

Consider first the series of wall-to-wall simulations summarized in Table 5.1. The independent, or controlled, variable in all of the dirty runs employing the wall-to-wall inventory option was the frequency of the inventory interval. All of the other variables were dependent and uncontrolled, having been accumulated daily as the runs proceeded. It was decided that a high correlation between inventory interval and record accuracy would allow comparisons to be made between record accuracy and any other of the dependent variables. Linear regression analysis resulted in a correlation coefficient of 0.89 for inventory interval and record accuracy for the first experiment with the whole sample of 561 items. This correlation coefficient was considered high enough to allow linear regression analyses between record accuracy and the other dependent variables.

Subsequently, linear regression analyses were made on record accuracy and the following, one at a time: the actual complete fills as a percentage

of total requisitions (COMPFL%), backorder releases (BOREL), the backorder-day total (BODTOT), warehouse refusals (REFUSL), the actual inventory investment (ACTOH$) and the difference between actual and recorded investment (ACTOH$ - RECOH$). A regression was not made on record accuracy and buys, since subjective evaluation of the results in Table 5.1 deemed it unnecessary. A t-test was made on each set of regression results, with an alpha of .05. The null hypothesis was that the slope of the regression line is zero, which would indicate no linear relation between record accuracy (the independent variable) and the dependent variable being considered. The regression results for this experiment are given in Table 6.1. A rejection of the null hypothesis indicated a linear relation; an acceptance of the null hypothesis indicated no linear relation.

These dirty wall-to-wall physical inventory results were interpreted as follows:

- Inventory record accuracy was strongly related to the wall-to-wall physical inventory interval, decreasing as the interval increases;
- As record accuracy decreased, the number of warehouse refusals increased, the actual inventory investment increased, and unrealized assets (ΔI = ACTOH$ - RECOH$) increased; and
- The requisition fill rate (COMPFL%) and the total backorder days (BODTOT) measures were <u>not</u> significantly affected by record accuracy.

Some of the results were expected and others were unexpected. Even though the wall-to-wall physical inventory was not error free, it provided the only opportunity to correct errors introduced in receipt and issue processing, other than the spot inventories. It followed, then, that accuracy

TABLE 6.1. CORRELATION AND REGRESSION RESULTS FOR

WALL-TO-WALL INVENTORIES, EXPERIMENT ONE

VARIABLES	CORRELATION COEFFICIENT	REGRESSION COEFFICIENTS $y = a + bx$ a	b	COMPUTED t VALUE	DEGREES OF FREEDOM	$t_{.05}$	ACCEPT OR REJECT
Interval vs. Accuracy	-0.890	93.14	-0.009	-16.665	74	1.645	R
Accuracy vs. BODTOT	-0.117	11.23	-0.054	- 1.316	125	1.645	A
Accuracy vs. COMPFL%	0.136	42.87	0.124	1.547	128	1.645	A
Accuracy vs. ΔI	-0.585	14.65	- 158	- 3.141	20	1.725	R
Accuracy vs. ACTOH$	-0.648	40.381	- 252	- 3.708	20	1.725	R
Accuracy vs. REFUSALS	-0.403	108	-0.919	- 4.965	128	1.645	R
Accuracy vs. BOREL	0.066	397	0.639	0.714	116	1.645	A

should have increased as the physical inventory frequency increased. It also seemed reasonable that as the inventory interval increased and accuracy decreased, that the number of warehouse refusals should have increased.

The fact that unrealized assets increased as accuracy decreased follows logically from the fact that errors were being introduced and that a pre-posting accounting scheme was employed. Negative errors (RECOH > ACTOH) would occasionally be caught as warehouse refusals. However, positive errors (ACTOH > RECOH) would not be discovered, except by a physical inventory. Hence, inventory assets and unrealized assets grew as the physical inventory interval increased.

The fact that supply effectiveness (COMPFL% and/or BODTOT) was not a function of record accuracy was unexpected. It must be remembered that this result was obtained under the following conditions: errors were introduced in issue and receipt processing and the physical inventories were not completely accurate. The correlation and regression analyses indicated weak relationships, positive for COMPFL and negative for BODTOT, but neither was strong enough to be significant with the variances present in these processes. This important result should alter the existing strategy for dealing with inventory record accuracy.

Subjective evaluation of the results of the prior-to-buying physical inventory policy (PBUY) in Table 5.1 indicated that this inventory produces approximately the same results as a wall-to-wall inventory policy with a 182 or 273 day inventory interval. Statistical t-tests, summarized in Table 6.2, indicated no significant difference between the PBUY averages and the overall wall-to-wall averages for COMPFL% and BODTOT. Thus, it was concluded that, whereas with wall-to-wall inventories, supply effectiveness

was not related to record accuracy, so also was supply effectiveness not related to the record accuracy produced by the PBUY inventory policy. An anomoly in the PBUY data is that ΔI = ACTOH$ - RECOH$, the unrealized assets, was negative. No explanation was readily found, though this result may have been simply due to variances.

TABLE 6.2. t-TESTS COMPARING AVERAGE

WALL-TO-WALL AND PBUY COMPFL% AND BODTOT

H_o: $\bar{X}_{WTW} - \bar{X}_{PBUY} = 0$

X	$\bar{X}_{WTW}$	S_X	$\bar{X}_{PBUY}$	t	Degrees of Freedom	$t_{.05}$	Accept or Reject
COMPFL%	54.01	2.37	53.80	0.089	128	1.645	A
BODTOT	6.41	1.20	6.30	0.088	125	1.645	A

Condered next were the clean runs summarized in Table 5.1. It was previously shown that supply effectiveness was the same under wall-to-wall or PBUY physical inventories, and not related to record accuracy. With the clean runs, record accuracy was 100%, by definition, and there are no warehouse refusals or unrealized assets.

Supply effectiveness was significantly higher in the clean runs than in the dirty runs; mean COMPFL% was 57.1% and 54.0% and mean BODTOT was 5.16 and 6.41 (million) for clean and dirty runs respectively. Both differences were significant at the 0.01 level, using a t-test for the equivalence of means with unequal variances (7).

One must remember the conditions on the various statements made about supply effectiveness and record accuracy. To summarize, it has been shown that supply effectiveness was significantly degraded by errors introduced in receipt and issue processing, and in physical inventory taking. However, given the introduction of errors, supply effectiveness was not influenced by the level of record accuracy (given the introduction of errors, 100% accuracy is, of course, not achievable).

Two other observations were made. The first was that the annual number of buys and the annual number of backorder releases were effectively constant throughout clean and dirty runs. The number of buys made was independent of whether or not errors were introduced and independent of the frequency and type of physical inventories taken. This was not an unexpected result. The constancy of the number of backorder releases was explained as a simulation model inadequacy. The model did not keep track of backorders by requisition but only in total. For this reason, it was not possible to make meaningful statements about backorder releases in any of the three experiments.

The final observation was related to the actual inventory investment, ACTOH$. This figure was the average dollar value of the stock actually held in inventory. The ACTOH$ information for this experiment, as given in Table 5.1, was plotted in Figure 6.1. From the figure, it was seen that certain of the dirty runs operated with <u>less</u> actual inventory investment than the clean system. Explanation of this phenomenon was as follows. There were two factors influencing ACTOH$: (1) the accumulation of positive errors and unrealized assets in a pre-posting system operated with errors, and (2) the backorder situation. Unrealized assets grew as

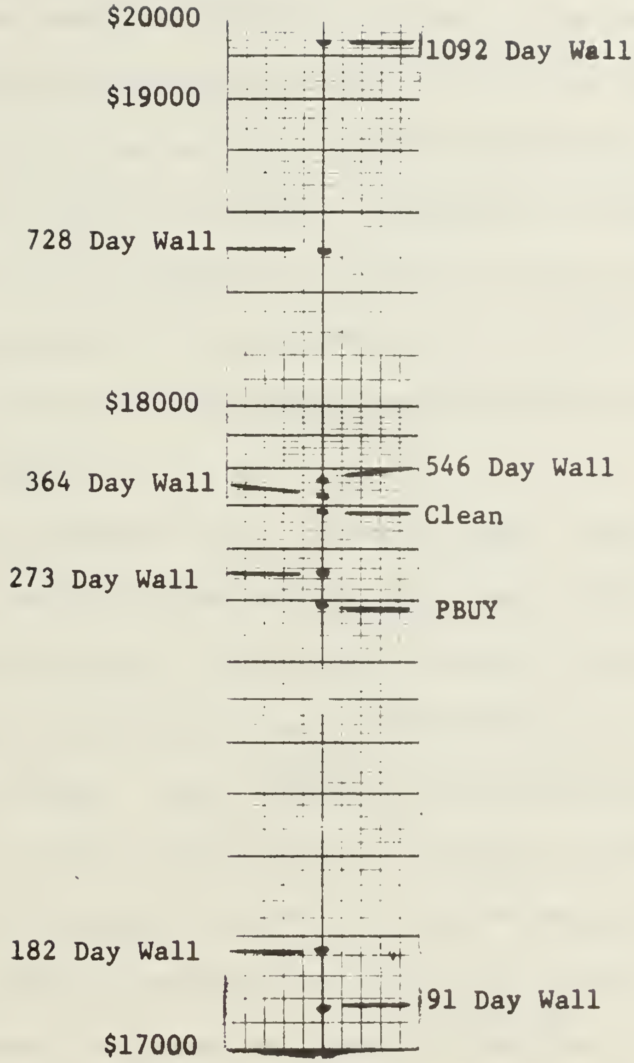

FIGURE 6.1. ACTUAL INVENTORY INVESTMENTS

(ACTOH$) IN EXPERIMENT ONE

record accuracy decreased. This implied the growth of ACTOH$ as, subject to record errors, RECOH$ was controlled by the reorder point-reorder quantity inventory policies. This growth of ACTOH$ was offset to some degree by the increased BODTOT of dirty operations over clean ones. With a higher number of backorders, stock turnover was increased because more material was back-order released, and never waited in inventory for demand to develop. Now, for very frequent wall-to-wall inventories, unrealized assets were held to a minimum and the extra million or so backorder days of the dirty wall-to-wall operations over clean operations reduced the ACTOH$ for the dirty runs below the clean ACTOH$ figure.

Errors and their influence on all phases of supply operations have been discussed but the question of the best way to conduct physical inventories has not yet been addressed. Two physical inventory schemes were considered: wall-to-wall inventories of various frequencies and a selected item inventory prior to buying. Other schemes are possible but were not considered. Presumably, supply effectiveness is the major objective or at least a major objective of inventory record accuracy and physical inventories. However, the analysis indicated that within the context of realistic operation (errors introduced and imperfect physical inventories), supply effectiveness was not influenced by the physical inventory policy. Hence, some other basis for selecting physical inventory policies had to be employed.

It was decided that the choice should be made on the basis of costs. For this purpose, the costs of operating the supply system were considered to be the following:

a. physical inventory costs;

b. investment costs of unrealized assets;

c. costs of warehouse refusals; and

d. actual stock investments.

Other variables, such as backorders and buys made, could not be included since they were independent of the physical inventory scheme employed.

For purposes of costing the various inventory policies studied, predicted costs based upon the regression analyses of Table 6.1 were used. The total costs of the various inventory policies are given in Table 6.3. From the table, it was seen that minimum costs were acheived by using a wall-to-wall inventory at 273 day intervals. These total costs were, of course, dependent upon the costs assumed for physical inventories. The costs used in Table 6.3 are system-wide averages. There were large cost differences from stock point to stock point within the Naval supply system. The PBUY inventory policy did poorly in Table 6.3 due to the relatively high cost of a selected item inventory.

The second and third experiments were similar to the first, but supplemented the results thus far obtained in several ways.

6.3 Analysis of the Second Experiment

In the second experiment, the basic 187 item sample was split into three groups according to annual demand. The high demand group contained 36 items with annual demand of 100 units or more and average demand of 720 units. The medium demand group contained 39 items with annual demand between 10 and 99 units and average demand of 31 units. The low demand group contained 112 items with annual demand of 10 units or less and

TABLE 6.3. PHYSICAL INVENTORY POLICY

COST ANALYSIS, EXPERIMENT ONE

PHYSICAL INVENTORY	PREDICTED ACCURACY	COST PHYS. INV.$	PREDICTED ΔI$	PREDICTED REFUSALS$	PREDICTED ACTOH$	TOTAL COST$
91 Wall	92.32	2463	65	91	17000	19619
102 Wall	91.50	1231	195	95	17197	18718
273 Wall	90.68	821	325	98	17395	18639
364 Wall	89.68	616	483	102	17636	18837
546 Wall	88.23	411	712	106	17986	19215
728 Wall	86.59	307	971	110	18381	19769
1092 Wall	83.31	205	1489	122	19171	20987
PBUY	91.40	2872	0	86	17495	20453

average of 4 units. Each sub-sample was expanded to a stock battery of 504 records. The simulation results were summarized in Tables 5.2, 5.3, and 5.4.

Stratification of the original sample into high, medium, and low demand categories produced the same results with regard to the relation between inventory interval and record accuracy as in the first experiment for the wall-to-wall physical inventories. The correlation coefficients of inventory interval and record accuracy were all high enough to justify comparisons between record accuracy as the independent variable and the other dependent variables. These coefficients, and the other regression results, are presented in Table 6.4.

Even though the levels assumed by the variables were different from those in the whole sample (see Table 5.1), the conclusions about the relations between record accuracy and the other variables remained the same. The requisition fill rate and the number of unit backorder days were <u>not dependent</u> upon record accuracy. Again, high record accuracy in an inventory system operating with errors did not produce a high level of supply effectiveness.

One should notice (Table 5.1) that the fill rate in the high demand sample was significantly lower than in the whole unstratified sample; the mean number of unit backorder days was significantly higher. The opposite conclusions held for the low demand sample. The range of record accuracy was highest in the high demand sample, and lowest in the low demand sample. Figure 6.2 indicated the decline of inventory record accuracy as the wall-to-wall inventory interval increased, for the whole sample and each of the demand stratified samples. The correlation coefficient (ρ) for each regression line was also indicated.

TABLE 6.4. CORRELATION AND REGRESSION RESULTS FOR WALL-TO-WALL INVENTORIES, EXPERIMENT TWO

VARIABLES	CORRELATION COEFFICIENT	REGRESSION COEFFICIENTS $y = a + bx$ a	b	COMPUTED t VALUE	DEGREES OF FREEDOM	$t_{.05}$	ACCEPT OR REJECT
HIGH DEMAND SAMPLE							
Interval vs. Accuracy	-0.949	93.20	-0.019	-20.832	49	1.645	R
Accuracy vs. BODTOT	0.026	25.781	0.016	0.235	83	1.645	A
Accuracy vs. COMPFL	-0.000	35.51	-0.000	- 0.001	85	1.645	A
Accuracy vs. ΔI	-0.969	25852	-279	-13.560	13	1.771	R
Accuracy vs. ACTOH	-0.530	76026	-386	- 4.333	49	1.645	R
Accuracy vs. REFUSALS	-0.179	66	-0.206	- 1.666	85	1.645	R
MEDIUM DEMAND SAMPLE							
Interval vs. Accuracy	-0.940	92.12	-0.010	- 8.682	11	1.796	R
Accuracy vs. BODTOT	-0.138	7.34	0.015	- 0.637	22	1.717	A
Accuracy vs. COMPFL	0.086	60.97	0.060	0.396	22	1.717	A
Accuracy vs. ΔI	-0.896	11767	-129	- 2.855	3	2.353	R
Accuracy vs. ACTOH	-0.963	38161	-211	- 5.082	3	2.353	R
Accuracy vs. REFUSALS	-0.706	132	-1.180	- 4.573	22	1.717	R
LOW DEMAND SAMPLE							
Interval vs. Accuracy	-0.751	92.60	-0.004	-4.694	18	1.734	R
Accuracy vs. BODTOT	0.316	-0.07	0.001	1.527	22	1.717	A
Accuracy vs. COMPFL	0.052	66.24	0.054	0.241	22	1.717	A
Accuracy vs. ΔI	-0.367	1686	-18	-0.558	3	2.353	A
Accuracy vs. ACTOH	-0.545	9825	-35	-0.918	3	2.353	A
Accuracy vs. REFUSALS	-0.517	127	-1250	-2.767	22	1.717	R

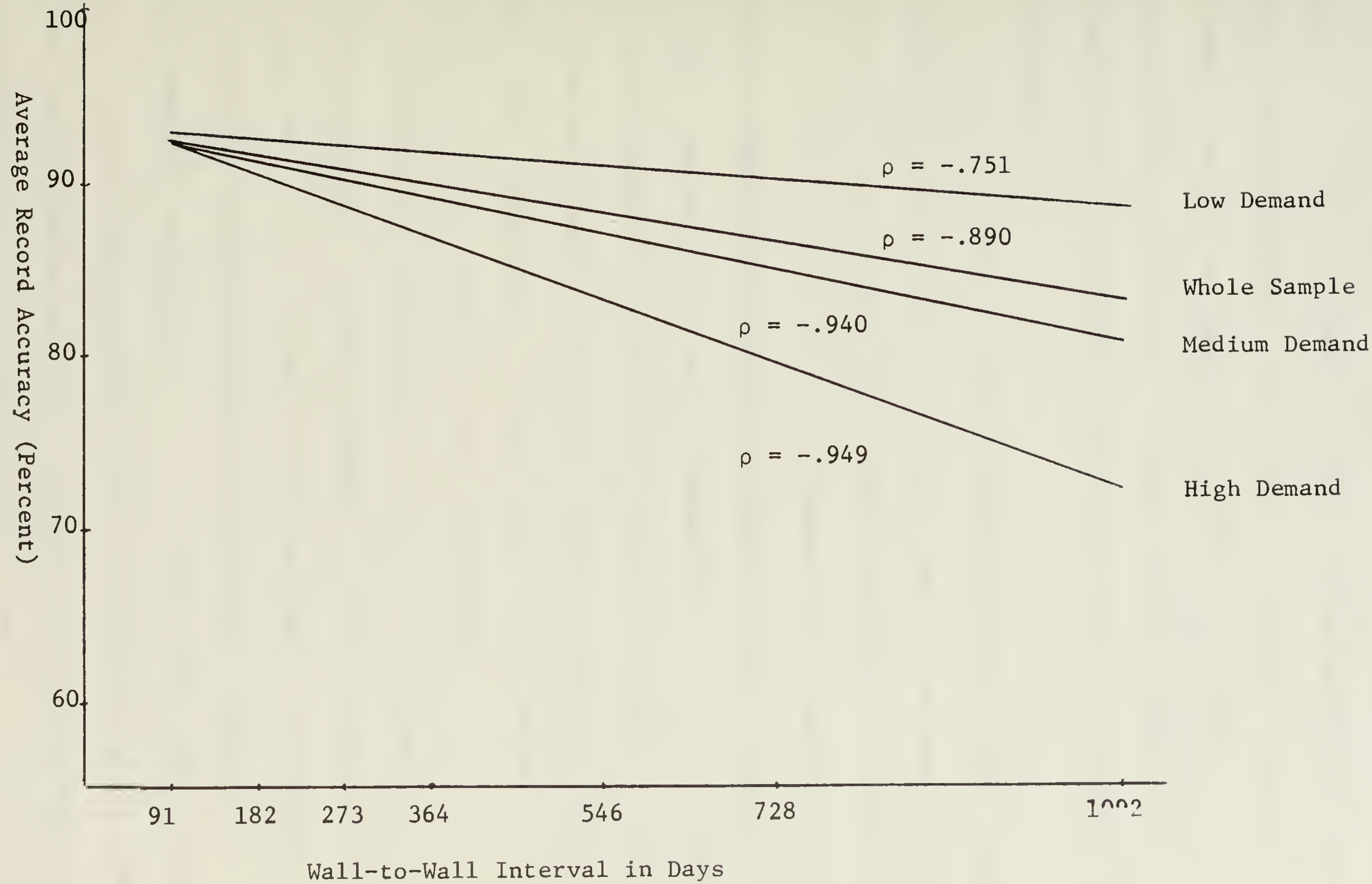

FIGURE 6.2. RECORD ACCURACY AS A FUNCTION OF THE WALL-TO-WALL INVENTORY INTERVAL

It was noted that the inventory control policies employed at NSC Newport at the time the data was taken (late 1965) were indeed curious. As summarized in Table 6.5, they provided a low requisition fill rate for high demand, low cost items and much higher fill rates for higher cost, low demand items. Item by item examples included a high-demand, one cent item with a negative safety level! At that time, NSC Newport was not using FMSO Variable Operating and Safety Level (VOSL) rules, but their own local inventory control policies.

As in the first experiment, cost analyses were made to determine the least-cost physical inventory policy for each of the demand stratified subsamples of the second experiment. These cost analyses are presented in Tables 6.6, 6.7, and 6.8. Table 6.6 indicated that a quarterly wall-to-wall physical inventory was optimal for items with annual demand in excess of 100 units. The results for medium-demand items, Table 6.7, indicated the cost effectiveness of an annual wall-to-wall inventory, but lacked precision, since many possible wall-to-wall intervals were not simulated. For low-demand items, Table 6.8, a triennial wall-to-wall inventory was indicated, although there was again a lack of precision.

An overview of Tables 6.6, 6.7, and 6.8 indicated that the PBUY selected-item inventory was never optimal, but that it became more attractive as item demand rate increased. Note also that all statements in this report concerning the PBUY selected-item inventory are based upon the most favorable operating conditions; i.e., in the simulation model, the scheduled inventory is in fact made immediately prior to buying the item. From conversations with NSC Oakland personnel, it was known that the PBUY policy in effect throughout most of the supply system for wholesale material was

TABLE 6.5. COST, DEMAND, AND FILL RATES

FOR WHOLE SAMPLE AND DEMAND-STRATIFIED SUBSAMPLES

	WHOLE SAMPLE	HIGH DEMAND	MEDIUM DEMAND	LOW DEMAND
Average Cost, $	6.10	1.51	4.04	8.29
Average Demand, Units Per Year	148	720	31	4
Average Requisition Fill Rate, %	57	38	66	71

TABLE 6.6. PHYSICAL INVENTORY POLICY COST ANALYSIS, EXPERIMENT TWO, HIGH DEMAND SAMPLE

PHYS. INV.	PRED. ACC.	COST PHYS. INV.	PRED ΔI	PRED. RFLS.	PRED ACTOH$	TOTAL$
91 W	91.47	2195	332	184	40719	43430
182 W	89.74	1110	815	188	41386	43499
273 W	88.01	730	1297	188	42054	44269
364 W	86.28	549	1780	188	42722	45239
546 W	82.83	368	2742	192	44054	47356
728 W	79.37	274	3708	196	45389	49567
1092 W	72.45	182	5638	200	48060	54080
PBUY	89.70	4813	0	149	40815	45777

TABLE 6.7. PHYSICAL INVENTORY POLICY COST ANALYSIS, EXPERIMENT TWO, MEDIUM DEMAND SAMPLE

91 W	91.21	2195	19	94	18916	21224
364 W	88.48	549	285	110	19492	20436
728 W	84.88	274	518	122	20260	21174
1092 W	81.20	182	1600	133	21028	22943
PBUY	88.40	2537	0	86	18696	21319

TABLE 6.8. PHYSICAL INVENTORY POLICY COST ANALYSIS, EXPERIMENT TWO, LOW DEMAND SAMPLE.

91 W	92.24	2195	26	47	6597	8865
364 W	91.14	549	46	51	6635	7281
728 W	89.69	274	72	59	6686	7091
1092 W	88.23	182	98	67	6737	7084
PBUY	93.30	1940	0	39	6677	8656

facing implementation problems. Rather than performing a scheduled inventory immediately prior to buying, the current system hoped to inventory in the same quarter in which a buy was anticipated. Further, only possibly 20% of the items were receiving even this type of service. Hence, the effectiveness of the PBUY selected-item inventory as predicted by the model represented an upper bound which could not be achieved in actual operations. From all indications, then, PBUY was not seen to be a particularly effective physical inventory policy.

6.4 Analysis of the Third Experiment

This experiment was suggested by the unexpected lack of a relationship between accuracy and supply effectiveness in the dirty runs of the first experiment. That supply effectiveness was significantly degraded by dirty operations had been shown. But another, and more important, influence of supply effectiveness came from the reorder point levels for the individual items. It was thought possible that in experiment one the reorder points were so low as to completely mask the influence of record accuracy. Therefore, experiment three was based upon much higher reorder points for each of the items.

In this experiment, the whole sample was used, as in the First Experiment. Fewer demand patterns were used as indicated in Table 5.5. All reorder points were recomputed so as to provide an 85% level of protection against stockout in a cycle.

Similar correlation and regression analyses, as in the first two experiments, produced a high correlation coefficient for record accuracy and wall-to-wall inventory interval. However, the same lack of dependence of supply effectiveness upon record accuracy was also found. See Table 6.9.

TABLE 6.9. CORRELATION AND REGRESSION

ANALYSES FOR THE THIRD EXPERIMENT

VARIABLES	CORRELATION COEFFICIENT	REGRESSION COEFFICIENTS $y = a + bx$ a	b	DEGREES OF FREEDOM	$t_{.05}$	ACCEPT OR REJECT
Interval vs. Accuracy	-0.906	90.72	-0.010	-9.097	1.729	R
Accuracy vs. COMPFL	0.183	75.43	0.116	1.317	1.645	A
Accuracy vs. BODTOT	-0.169	2.72	-0.018	-1.215	1.645	A

It was therefore concluded, admittedly on the basis of only two data points, that the lack of relationship between record accuracy and supply effectiveness in dirty operations was independent of the basic level of protection as determined by item reorder points.

Other items of interest noted when comparing the results of the first and third Experiments were that to achieve the 31% increase in the requisition fill rate required a 250% increase in average inventory investment (from $18,000 to $48,000). Along with the increased assets and requisition fill rate, there was a corresponding decrease in backorder days, backorder releases and warehouse refusals.

7. SUMMARY AND CONCLUSION

The analysis of the inventory record accuracy problem presented in this report was based upon a simulation model thought to be sufficiently realistic, and upon the best error introduction, item and physical inventory cost data that could be obtained. The only process known to have been omitted from the model was the theft of warehouse materials.

The results have shown that the introduction of errors into inventory records and the lack of a perfect method for periodically reconciling the records do degrade supply operations. The deliterious effects of errors were seen in the requisition fill rate and backorder situation, in the generation of warehouse refusals, in the inventory assets actually held, and in unrealized assets.

The most significant result, however, was that when 100% accuracy was not obtainable, inventory record accuracy did not affect supply effectiveness. This result was demonstrated on a random sample of NSC Newport DSA items with reorder points that provided 54% and 85% fill rates and with high, medium, and low demand subsamples.

Cost analyses indicated the apparent superiority of the wall-to-wall physical inventory over the prior-to-buying selected-item physical inventory. These cost analyses indicated the optimal record accuracy level; that is, the level of accuracy corresponding to physical inventory policy which minimized the system costs which vary with the physical inventory policy. This is believed to represent the first determination of optimal record accuracy - given any definition of that term.

The superiority of the wall-to-wall inventory came from its low cost per item inventoried, relative to a selected-item inventory. It is recognized that most stock points in the Naval Supply System do not use a wall-to-wall physical inventory. Two further remarks seem to be in order. First, it would seem worthwhile to determine precisely why most stock points "cannot" utilize a wall-to-wall inventory. The second remark is that the results of this study seem to indicate that study of a stock point physical plant could be profitable. For example, the second experiment indicated that high demand items should be inventoried quarterly while low demand items should be inventoried only every three years. Within the context of record accuracy, great economies could be achieved by creating warehouses of homogeneous-demand items. What this might do to total stock point operations is not clear, but study is indicated as desirable.

Much has been learned about the effects of inventory record accuracy on supply operations. However, it is still desirable to investigate other physical inventory policies and other item populations. In any case, the model provides a means for evaluating any proposed physical inventory policy prior to its implementation. A companion report to this one is being prepared and will be devoted exclusively to the simulation program partially described here. The purpose of the companion report is to allow anyone to use the simulation program with a minimum of difficulty.

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APPENDIX A. SIMULATION PROGRAM LABELS

ABOREL:	Number of Attempted Backorder Releases For Year.
ACOMFL:	Number of Attempted Completely Filled Requisitions For Year.
APARFL:	Number of Attempted Partially Filled Requisitions For Year.
ACTOH(I):	Actual On-Hand Quantity For Ith Item.
ACTOH$(I):	Dollar Value of Actual On-Hand Inventory For The Ith Day.
BO(I):	Amount of Material Backordered For Ith Item.
BODAYS(I):	Number of Backorder Days For Ith Item For Year.
BOREL:	Number of Actual Backorder Releases for Year.
BODTOT:	Total Unit Backorder Days At End of Year For That Year.
BUY:	Subroutine for Checking Inventory Position on an Item, and Initiating a Buy if Necessary.
BUYS:	Number of Buys For A Year.
BUY$(I):	Dollar Value of Buys for Ith Quarter.
COMPFL:	Number of Actual Completely Filled Requisitions For Year.
CUMREQ:	Number of Requisitions For Year
DBAR(I):	Mean Quarterly Demand on Ith Item (Data)
DUEDAT(I):	Due Date of Material Ordered on Ith Buy For The Item Number Contained in Index (I).
DUES(I):	Amount of Material Due in For The Ith Item.
FINISH:	Day on Which Simulation Terminates.
IFLAG:	Flag Generated During Requisition Processing Which Determines for ISSERR Subroutine Whether ISSQN should be COMPFL or a PARTFL.
INDEX(I):	Contains Item Number For Ith Buy.
INVOP:	Inventory Option (Wall or PBUY).
ISBOER:	Subroutine For Making Backorder Releases With Errors.

ISSERR: Subroutine For Making Requisition Issues With Errors.

ISSOK: Number of Requisitions Issued Without Error For Year.

ISSEO: Number Of Requisitions Overissued For Year.

ISSEU: Number of Requisitions Underissued For Year.

ISSWID: Number of Requisitions In Which Wrong Stock Number Was Issued For Year.

ISSQN: Issue Quantity; Used in Both Issue and Backorder Release Subroutines.

LT(I): Mean Procurement Lead Time For Ith Item (Data).

MAD(I): Mean Absolute Deviation of Quarterly Demand For Ith Item (Data).

NEWREC: Item Number of New Record Chosen At Random By Subroutine NUREC.

NU(I): Parameter For Exponential Demand Distribution For Ith Item (Computed From Data).

NUREC: Subroutine For Randomly Selecting Record in Same Price Range As Record Under Consideration.

NXTREQ(I): Day of Next Requisition on Ith Item (Recomputed Every Time a Requisition is Received on Ith Item).

ORDQN(I): Quantity of Material Ordered on Ith Buy For Item Number Contained in INDEX(I).

P(I): Parameter Of Geometric Distribution Employed in Determination of Requisition Size (REQSIZ) On Ith Item (Computed From Data).

PARTFL: Number of Actual Partially Filled Requisitions For Year.

PBUY: Prior-to-Buy Inventory Option.

PRICE(I): Unit Price of Ith Item (Data).

RECACC(I): Proportion of Records Accurate At End of Ith Day.

RECOH(I): Recorded On-Hand Quantity for Ith Item.

RECOH$(I): Dollar Value of Recorded On-Hand Inventory for The Ith Day.

RECTOK: Number of Receipts Processed Without Error For Year.

RECTEO: Number of Receipts For Year With Quantity Actually Received Greater Than Quantity Ordered.

RECTEU:	Number of Receipts Processed For Year With Quantity Actually Received Less Than Quantity Ordered.
RECTNP:	Number of Receipts For Year With No Posting To Recorded On-Hand and Dues Fields Of Records.
RECTPW:	Number of Receipts For Year With Quantity Posted To Recorded On-Hand Field of Randomly Selected Record, Using NUREC Subroutine.
REFUSL:	Number of Warehouse Refusals For Year.
REQSIZ:	Requisition Quantity Generated From Geometric Distribution Upon Receipt of a Requisition.
RP(I):	Reorder Point For Ith Item (Data).
SERIAL(I):	Stock (Item) Number (Sequential From 1, 2, ...) Of Ith Item
SPOT:	Subroutine For Conduction Spot Inventory; Called Every Time a Warehouse Refusal is Generated, or With PBUY Physical Inventory.
TODAY:	Current Date (Integer Number, Begins With 1).
WALL:	Wall-to-Wall Inventory Option.
WALINT:	Interval Between Wall-to-Wall Inventories; Provided by User.
WALLOP:	Subroutine For Conducting Wall-to-Wall Inventories and Producing Certain Statistics Pertinant To The Period Just Preceding The Inventory.

APPENDIX B. THE STUTTERING POISSON PROCESS

Let the total quantity of item i demanded up to time t be denoted by $X_i(t)$ and let $S_i(t) = \sum_{n=1}^{N_i(t)} Y_{in}$, in which Y_{in} is the quantity demanded on the n^{th} requisition for item i and $N_i(t)$ is the number of requisition received up to time t .

It is assumed that $\{N_i(t), t \geq 0\}$ is a Poisson process and that $\{Y_{in}, n = 1,2,\ldots,N_i(t)\}$ is a family of independent, identically-distributed random variables distributed geometrically with probability mass function

$$P_Y(y) = p(1 - p)^{y-1} \qquad \text{for } y = 1,2,\ldots$$

$$= 0 \qquad \text{otherwise.}$$

The time between occurrences of requisitions for item i is an exponentially distributed random variable under the Poisson arrival assumption. The density function is given by

$$f_T(t) = \nu e^{-\nu t} \qquad \text{for } t \geq 0$$

$$= 0 \qquad \text{otherwise.}$$

A stochastic process such as $\{X(t)\}$ is termed a compound Poisson process; the particular compounding with a geometric distribution is

sometimes called a "stuttering Poisson" process. It is shown by Parzen [8] that the compound Poisson process $\{X(t), t \geq 0\}$ has the following properties:

$$\Phi X_i(t)^{(u)} = e^{\nu t(\Phi_{Y_i}(u) - 1)}$$

where $\Phi_{Y_i}(u)$ is the common characteristic function of the independent, identically-distributed random variables $\{Y_{in}\}$ and ν_i is the mean rate of occurrence in the event that a requisition is received for item i ; additionally,

$$E[X_i(t)] = \nu_i tE[Y_i] \tag{1}$$

$$Var[X_i(t)] = \nu_i tE[Y_i^2] \ . \tag{2}$$

The item data described in Section 4.3, contains information on estimated mean quarterly demand (DBAR), and the mean absolute deviation of quarterly demand (MAD). These parameters are used to estimate the parameters of the stuttering Poisson demand distribution for each item in the stock battery. Because the simulation unit time-step is one day, the parameters of the exponentially distributed interarrival time for item requisitions must be expressed in days.

Mean daily demand, μ_i , is determined as

$$\mu_i = \frac{DBAR_i}{91} \tag{3}$$

assuming 91-day quarters. The variance of daily demand, σ_i^2 , is

$$\sigma_i^2 = \frac{1}{91}\left(\frac{MAD_i}{.8}\right)^2 , \tag{4}$$

assuming that the standard deviation of quarterly demand is MAD/.8 .

The stuttering Poisson is completely specified by the parameters ν and p for the exponential and geometric distributions respectively. For geometric distribution

$$E[Y_i] = \frac{1}{p_i} \tag{5}$$

and

$$E[X_i^2] = \frac{(1-p_i) + 1}{p_i^2} \tag{6}$$

Setting t equal to one day, equations (1) and (2) become the equations for the mean and variance of daily demand μ_i and σ_i^2 . Using equations (5) and (6) it follows that

$$E[X_i(1)] = \nu_i E[Y_i] = \frac{\nu_i}{p_i} = \mu_i , \tag{7}$$

$$Var[X_i(1)] = \nu_i E[Y_i^2] = \frac{(2-p_i)\nu_i}{p_i^2} = \sigma_i^2 , \tag{8}$$

where μ_i and σ_i^2 are given by equations (3) and (4).

The solution of equation (7) yields $\nu_i = p_i \mu_i$. Substitution of this relationship into equation (8) yields, after some algebra,

$$p_i = \frac{2\mu_i}{\sigma_i^2 + \mu_i}$$

and

$$\nu_i = \frac{2\mu_i^2}{\sigma_i^2 + \mu_i}$$

In this manner, the parameters of the stuttering Poisson demand distribution are computed for each item from DBAR and MAD information on each item.

APPENDIX C

FLOW CHARTS FOR SELECTED PORTIONS

OF THE SIMULATION PROGRAM

SYSTEM FLOW CHART

Initialize arrays and variables.

Read in data.

Query user for length of simulation, inventory option, type of run (clean or dirty), and random number streams initializer (INITRN).

Generate due dates for dues outstanding on first day.

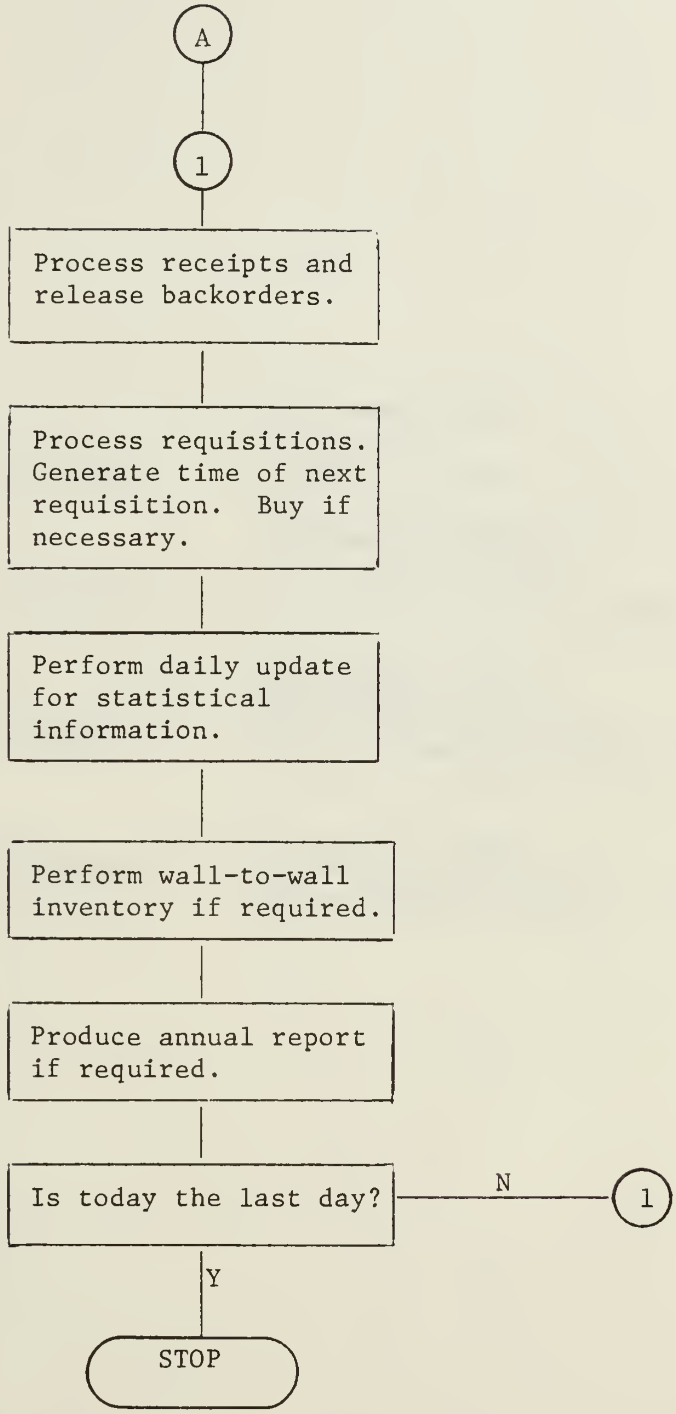
Compute parameters P and NU for geometric and exponential distributions for each item.

Generate time of first requisition for each item.

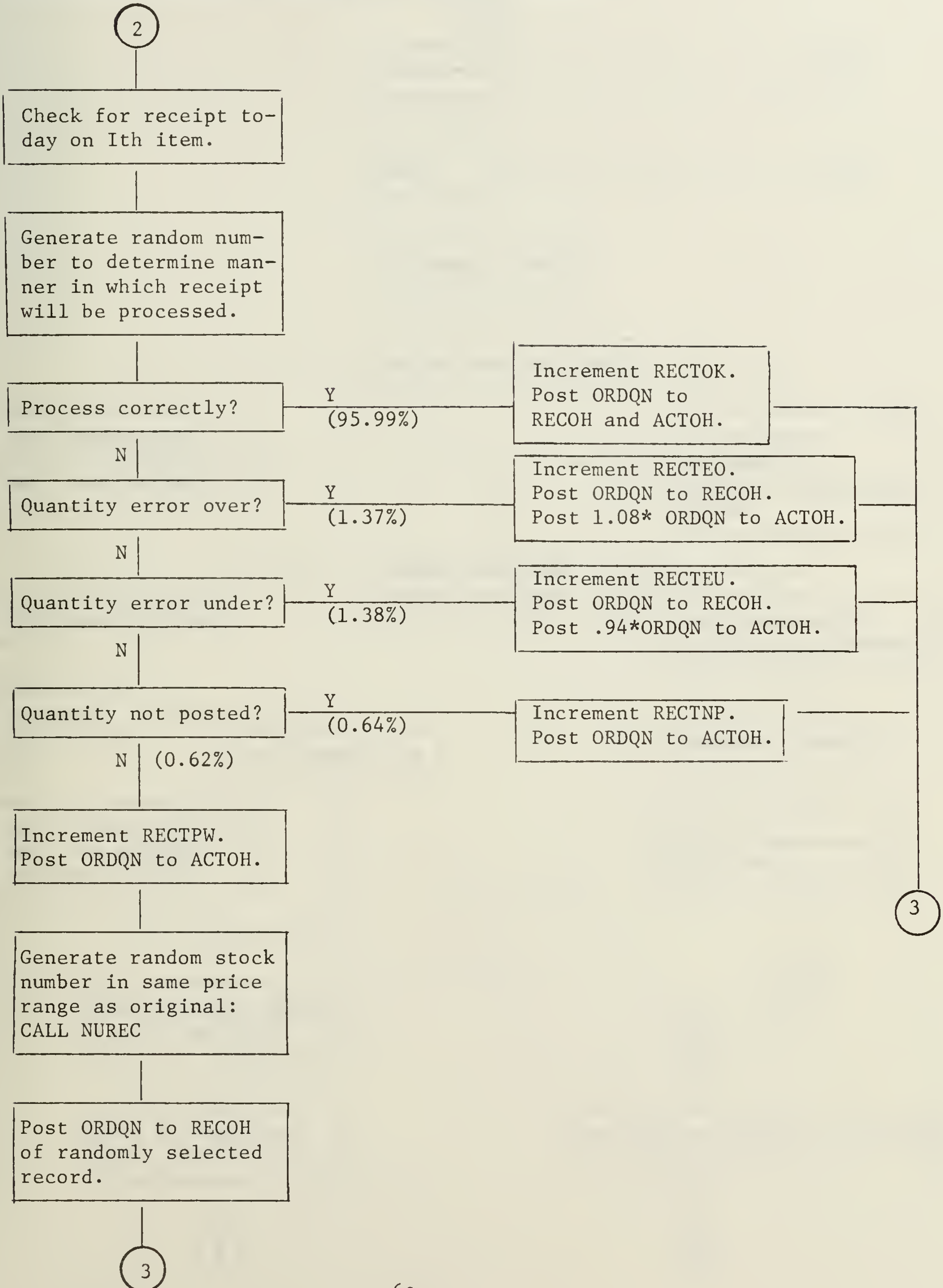
Generate first day buys based on initial inventory position.

A

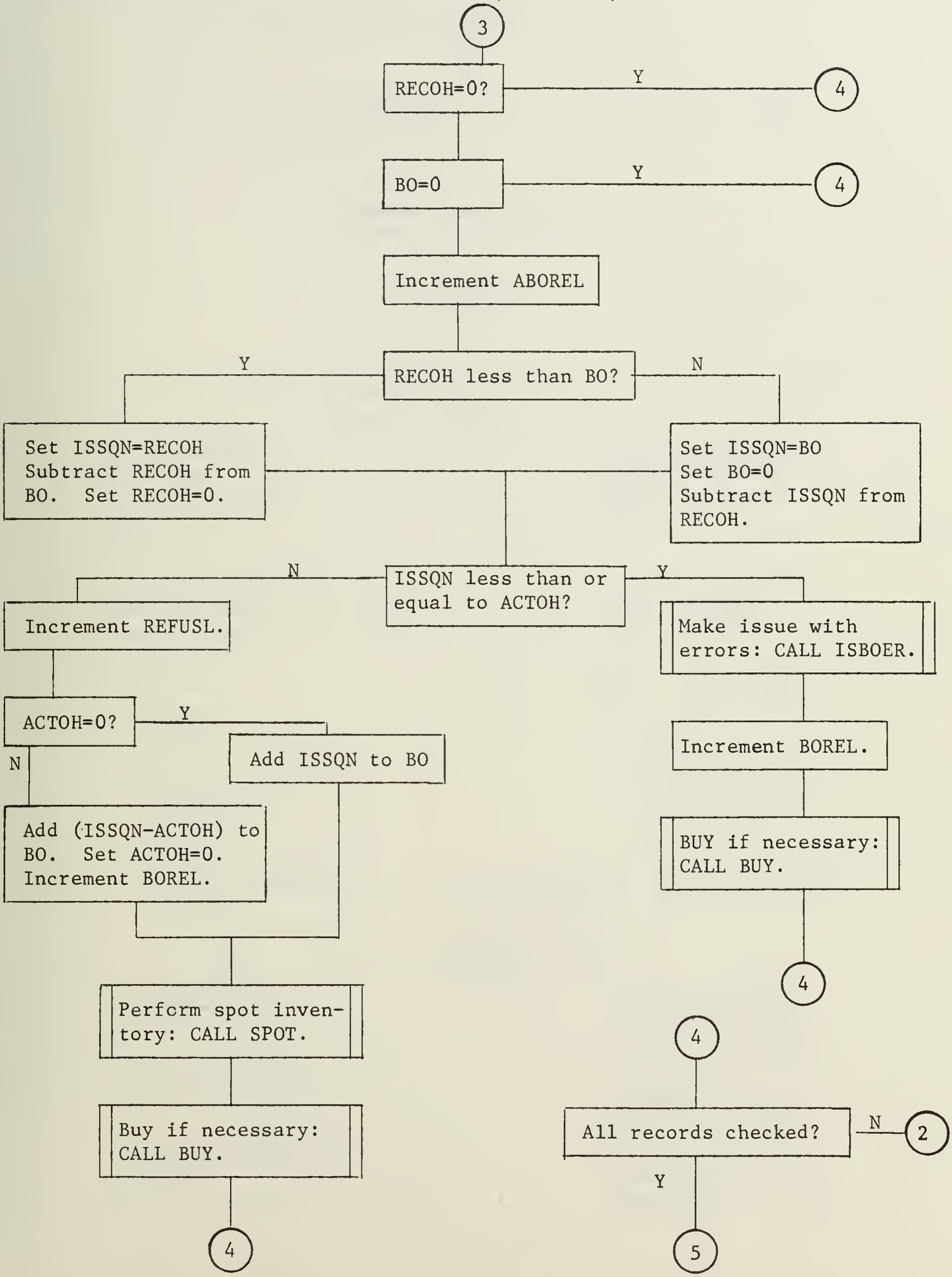
SYSTEM FLOW CHART (continued)



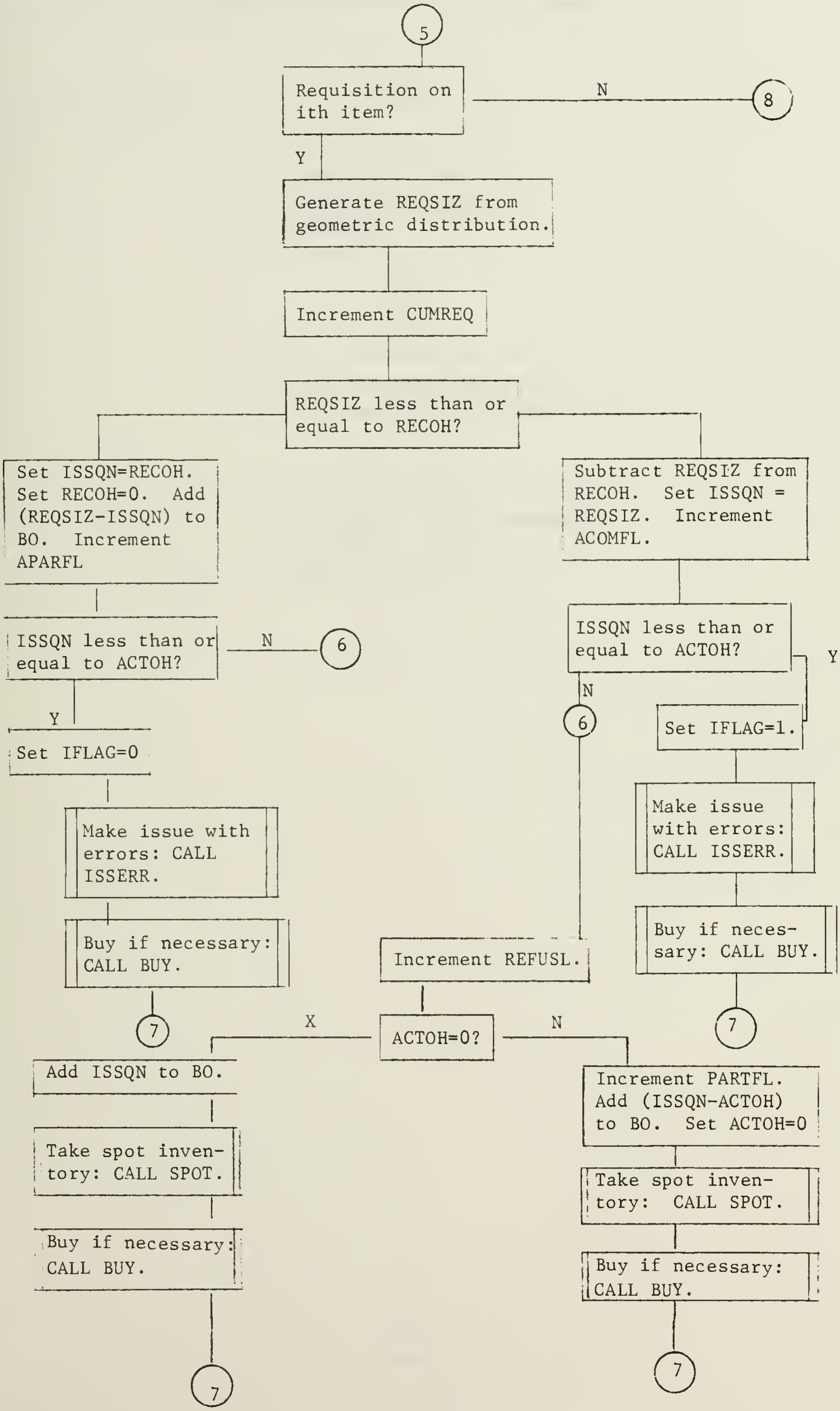
PROCESS RECEIPTS AND RELEASE BACKORDERS



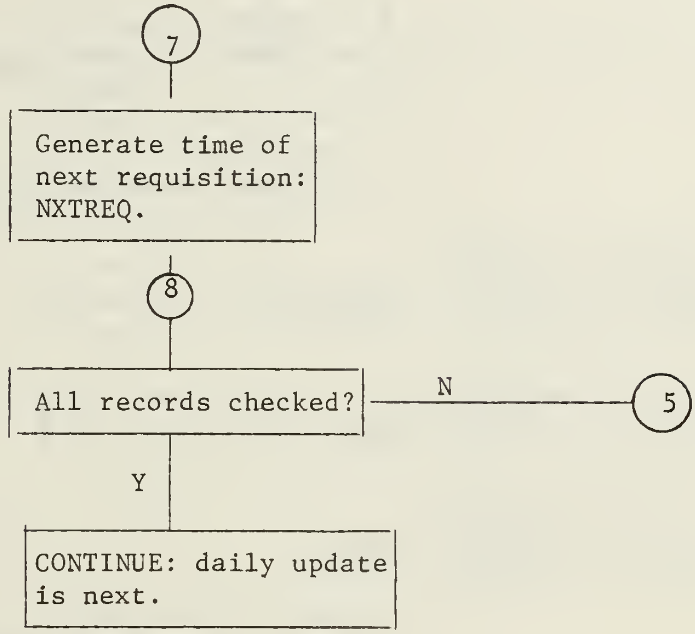
PROCESS RECEIPTS AND RELEASE BACKORDERS (continued)



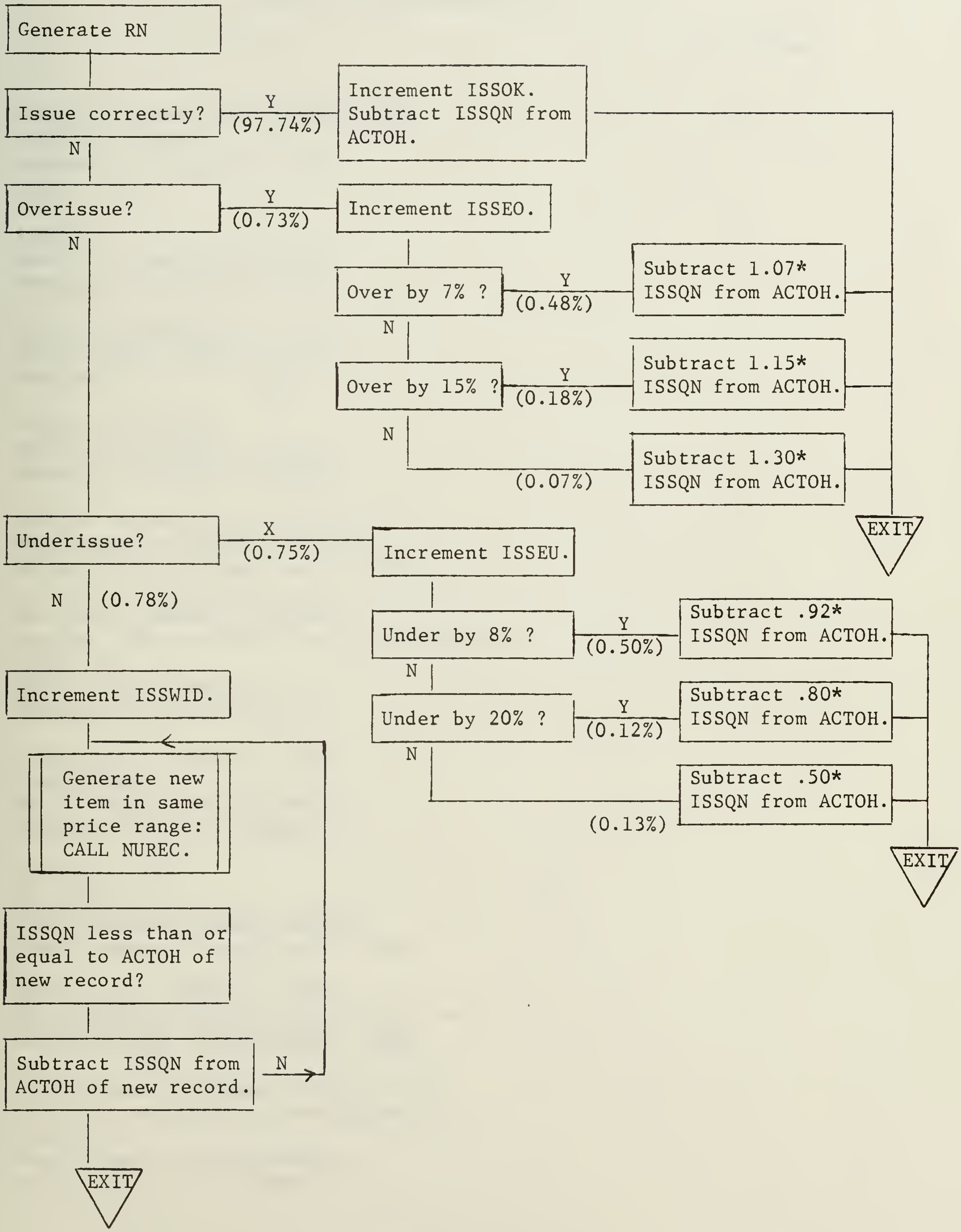
PROCESS REQUISITIONS



PROCESS REQUISITIONS (continued)



SUBROUTINE ISBOER: Issue (release) backorders with errors.



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13. ABSTRACT

The inventory record accuracy problem was studied using a complex simulation model of stock point supply operations. Complete item and error data were obtained from various sources within the Navy Supply System. The experiments performed indicate that the presence of stock record errors degraded supply operations, in terms of quantified measures, and that in an environment of imperfect receipt and issue processing and physical inventories, supply effectiveness was not related to record accuracy. A rational criterion for determining the optimal physical inventory policy was developed.

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